... resistance is connected in series with the armature of a series motor. The No-Volt release coil is connected in series with the armature. After closing the supply, the handle is moved from OFF position. Then full starting resistance is included. ∴ the starting current is reduced. Then the starting resistance is gradually cut down and the motor gathers speed, which will then develope back emf. Now the NVC gathers sufficient magnetism to hold the starter handle in RUN position. Hence this NVC is also called as hold on coil.

The main problem in case of DC series motor is it's over speeding action when the load is less. This problem can be presented by using two point starter. All the other coil's operation are same as used in the three point and four point starter.

⇒ **Starters for Three Phase Induction Motor:**

Necessity of starter:

When a 3ϕ supply is connected to a stator of a 3ϕ Induction motor, a rotating magnetic field is produced and the rotor starts rotating.

* Thus, a 3ϕ Induction motor is self starting.
* At the time of starting the motor slip is unity and the starting torque is very large.

(8)

The necessity of the starter is not only to start the motor but also,

(i) Reduction of the heavy starting current
(ii) Overload and No-load protection.

In general, 3ϕ Induction motor may be started either by connecting the motor directly to the full voltage of the supply or by applying a reduced voltage to the motor during starting period. The torque of an induction motor is proportional to the square of the applied voltage.

Starters on the stator side (or) squirrel cage starters

It's only for squirrel cage Induction Motors.

(i) Direct ON-line starter
(ii) Stator resistance starter
(iii) Star - Delta Starter
(iv) Auto transformer starter.

Starter on the Rotor side (or) slip ring starters:

It's only for slip ring Induction Motors

(i) Rotor Resistance starter.

⇒ (i) **Direct on-line (DOL) starter:**

We know that,

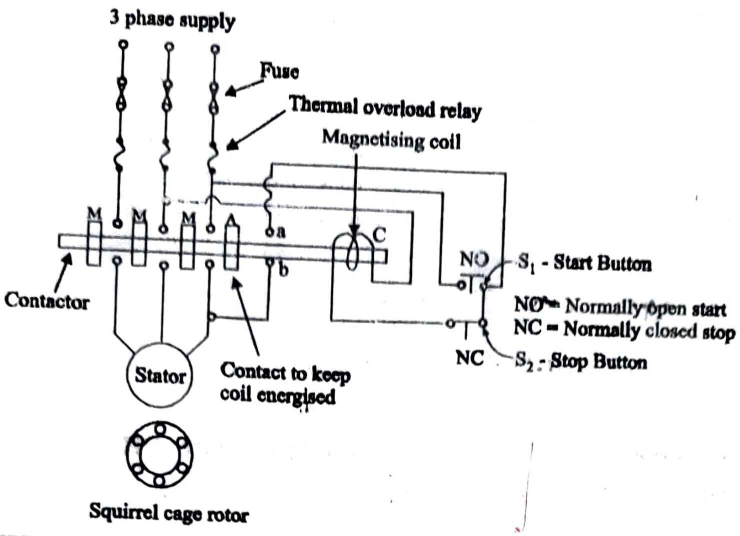
$$\text{Rotor input} = 2\pi N_s T = KT$$

Also, rotor Cu. loss = S * rotor input

$$\therefore 3I_2^2 R_2 = S * KT \qquad [\because T \propto I_2^2/S,\ R_2 \text{ is constant}]$$

Now

$$I_2 \propto I_1 \qquad \therefore T \propto I_2^2 / S$$



At starting moment, $s = 1$. $\therefore T_{st} \propto I_{st}^2 \rightarrow (1)$

If I_f = Normal full-load current and

s_f = full Load slip

then, $T_f \propto I_f^2 / s_f \rightarrow (2)$

$\frac{(1)}{(2)} \Rightarrow$

$$\therefore \frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 \cdot s_f$$

When motor is direct-switched onto normal voltage, then starting current is the short-circuited current I_{sc}.

$$\therefore \frac{T_{st}}{T_f} = \left(\frac{I_{sc}}{I_f}\right)^2 \cdot s_f$$

$$= a^2 \cdot s_f$$

where

$$a = \frac{I_{sc}}{I_f}$$

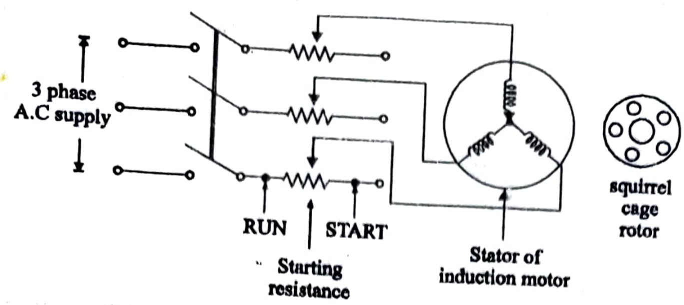
In the direct on line method of starting cage motors, the motor is directly connected to the 3 phase supply.

It consists of a coil-operated contactor 'c' controlled by start and stop push button switch from the starter. On pressing the START push button S_1 the conductor [illegible] gised from two line conductors L_1 and L_2. The three main contacts and the auxiliary contact A lose and the therminals 'a' and 'b' are short-circuited. The motor is thus connected to the supply when the pressure on S_1 is released, it moves back under spring action. Even then the coil 'c' remains energised through 'ab'. Thus the main contacts M remains closed and the motor continues to get supply. For this reason, contact 'A' is called hold-on circuit.

When the stop button 'S_2' is pressed, the supply through the conductor coil 'c' is disconnected. since the coil 'e' is de-energised, the main contacts M and auxiliary contact 'A' are opened. The supply to the motor is disconnected and the motor stops.

(ii) Stator Resistance starter (or) Primary Resistance starter:

By using Primary resistance the applied Voltage/Phase can be reduced by a fraction "x" and it additionally improves the power factor.



$I_{st} = x \cdot I_{sc}$ and $T_{st} = x^2 T_{sc}$

so $\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 \cdot s_f$

$= \left(\frac{x \cdot I_{sc}}{I_f}\right)^2 \cdot s_f$

$= x^2 \cdot \left(\frac{I_{sc}}{I_f}\right)^2 \cdot s_f$

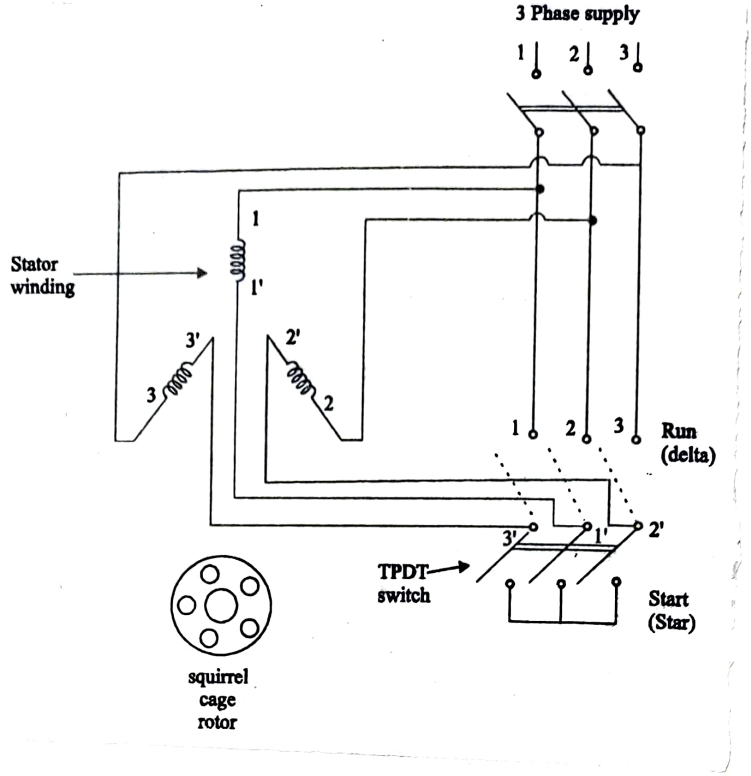
$\frac{T_{st}}{T_f} = x^2 \cdot a^2 \cdot s_f$

By applying a reduced voltage, we can reduce the starting current. For this, we are adding 3 reheostate in series with the 3 phase induction motor.

* Initially the rheostat is kept in maximum position, hence a minimum the voltage is applied to the motor.
* As the voltage is minimum, the motor will be started with a reduced starting current.
* As the motor gathers speed, the rheostat will be brought to minimum position thereby the full supply voltage is given to the Motor. Now motor will run at normal speed.

The stator construction is simple and cheap. As the ratio of starting torque to full load torque is x^2 as that of direct switching (DOL) starter, this method is useful [illegible] only.

(iii) Star - Delta Starter:



In DOL starter voltage across each Phase is $V/\sqrt{3}$ and starting current is $I_{st} = I_{sc}$.

In ~~~~ Y/Δ starter, $I_{st} = \frac{1}{\sqrt{3}} I_{sc}$ Per Phase

Now,

$$T_{st} = I_{st}^2 \quad [s=1]$$

$$T_f = I_f^2 / s_f$$

$$\therefore \frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 \cdot s_f$$

$$= \left(\frac{I_{sc}}{\sqrt{3}\, I_f}\right)^2 \cdot s_f$$

$$= \frac{1}{3}\left(\frac{I_{sc}}{I_f}\right)^2 \cdot s_f$$

$$\frac{T_{st}}{T_f} = \frac{1}{3} \cdot a^2 \cdot s_f$$

This star-delta method is cheap and effective provided by a moderate starting torque [1.5 times full-load torque].

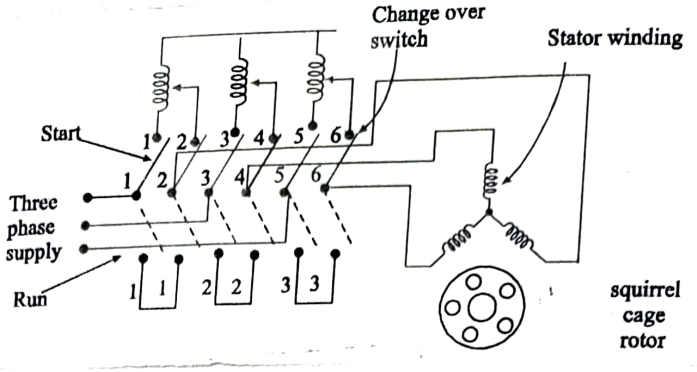
* This method is used in motors which are built in, run normally with a delta connected stator winding.
* It consists of a two way switch, which connects the motor in star for starting and then in delta for normal running.
* When the two way switch is at START position, the stator windings are connected in star. ∴ the applied voltage is reduced by a factor of $1/\sqrt{3}$
* For star connection, $V_{ph} = V_L/\sqrt{3}$. Hence the starting current is reduced. When the motor speed reaches 70 to 80% of normal speed, the switch is changed to RUN position where the motor is connected in delta.
* ∴ Full voltage is applied to the motor in the running condition.

(iv) Auto transformer starter:

An auto-transformer starter is suitable for both star and delta connected motors.

* In this method, the starting current is limited by using a 3 phase auto transformer to reduce the initial stator applied voltage.
* The auto transformer is provided with a number of tapping arrangements.
* Here, a double throw switch is used to connect the auto-transformer in the circuit for starting.

90



* When the handle of the switch is in the START position, the primary of the auto. transformer is connected to the supply line and the motor is connected to the secondary of the transformer.

With auto-starter, motor's voltage/phase $= KV/\sqrt{3}$

$$\therefore I_{st} = K I_{sc}$$

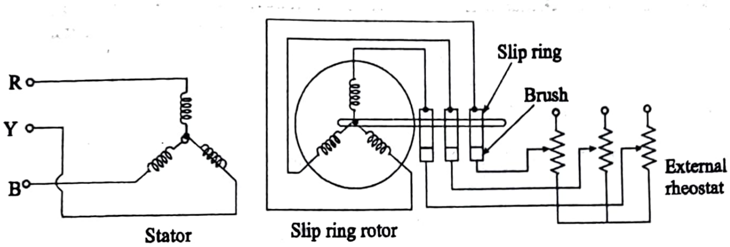
$$T_{st} \propto I_{st}^2 \ (S_{st}=1) \text{ and } T_f = \frac{I_f^2}{s_f}$$

$$\therefore \frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 s_f \ \text{(or)} \ \frac{T_{st}}{T_f} = K^2\left(\frac{I_{sc}}{I_f}\right)^2 \cdot s_f$$

$$\frac{T_{st}}{T_f} = K^2 \cdot a^2 \cdot s_f$$

When the motor picks up speed (say 80% of it's rated value), the change over switch (handle) is moved to the RUN position, the auto-transformer is disconnected from the circuit and the motor is directly connected to the line and get it's full rated voltage. The handle is held in the RUN position by the under voltage relay. In case the supply voltage fails (or) falls below a certain value, the handle is released and return back to the OFF position.

(v) Rotor Resistance starter:-



* This starter can be used only for slip-ring induction motor.
* Here external (or) starting resistance is connected in the rotor terminals.
* In this method, the motor is always started with full line voltage, applied across the stator terminals.
* The value of starting current is adjusted by introducing a variable resistance in the rotor circuit.
* At starting, the full resistance is included and hence the starting current is reduced.
* The resistance is gradually cut out of the rotor circuit as the motor gathers speed.